PATH TO 5G: KEY TECHNOLOGIES

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Samsung

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CONTENTS

1. 5G VISION

SAMSUNG

Enabling the Immersive Service Experiences

Ubiquitous Health Care

Wearable/Flexible Mobile Device

Mobile Cloud

UHD Video Streaming

Smart Map/Navigation

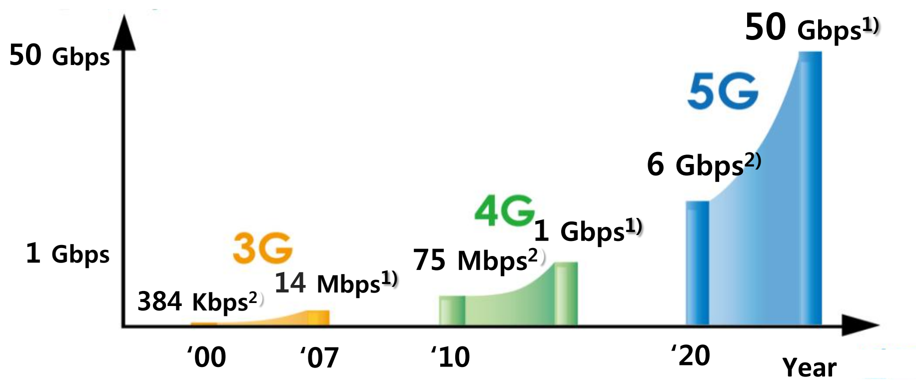
Real-Time Interactive Game

5G Performance Targets

Gigabit experience anywhere

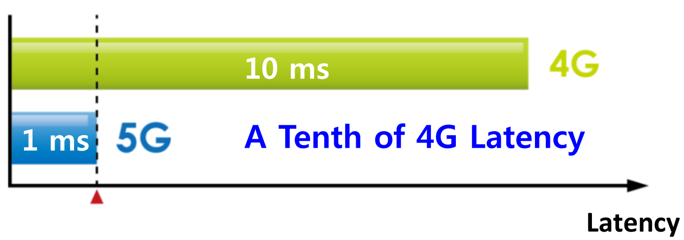
5G Performance Targets

Peak Data Rate > 50 Gbps

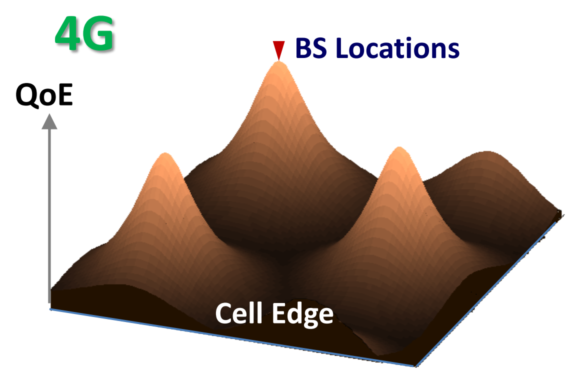


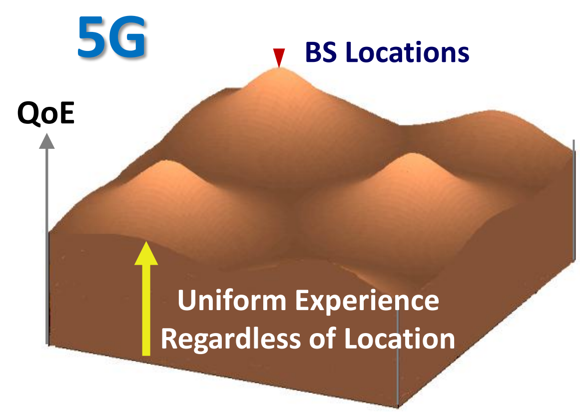
1) Theoretical Peak Data Rate 2) Data Rate of First Commercial Products

Latency < 1 msec



Anywhere 1 Gbps





2. Path to 5G: Key Technologies

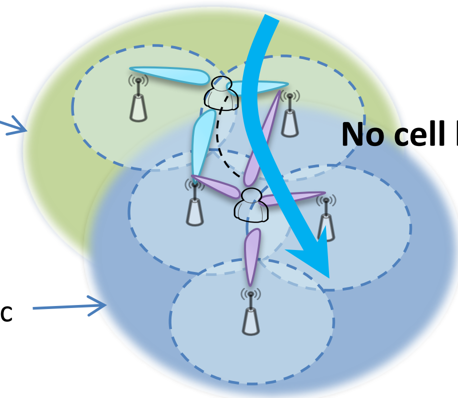
Path to 5G: Key Technologies (1/2)

mmWave System Tech.

Peak Rate 1 Gbps → **Peak Rate 50 Gbps**

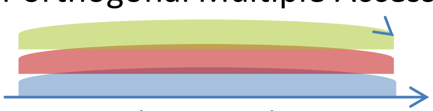
4G frequencies **New higher frequencies**

Adv. Small Cell



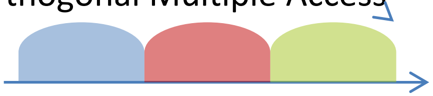
Adv. Coding & Modulation

Non-orthogonal Multiple Access

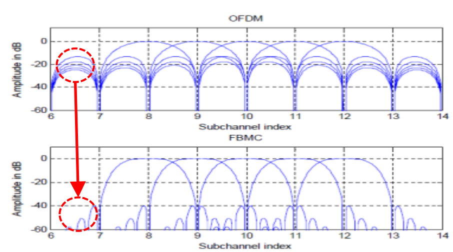


Time/Frequency/Space

Orthogonal Multiple Access

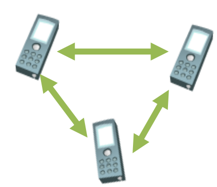


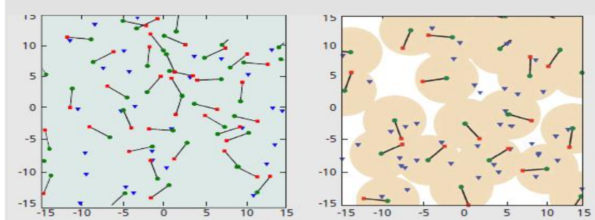
Time/Frequency/Space



Filter-bank Multi-carrier

Device-to-Devie (D2D)

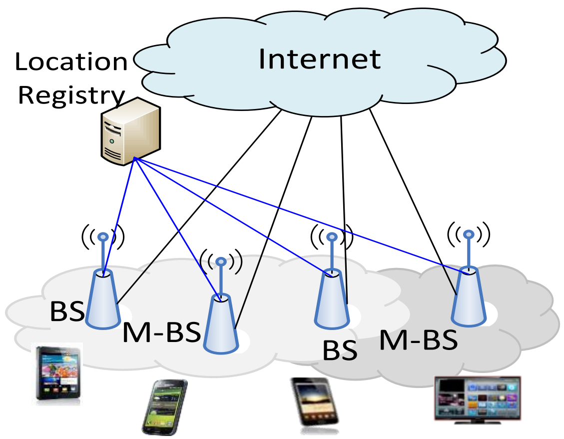




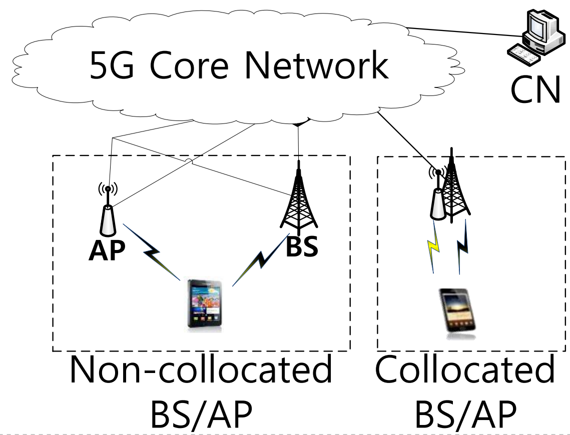
Enhancing areal spectral efficiency

Path to 5G: Key Technologies (2/2)

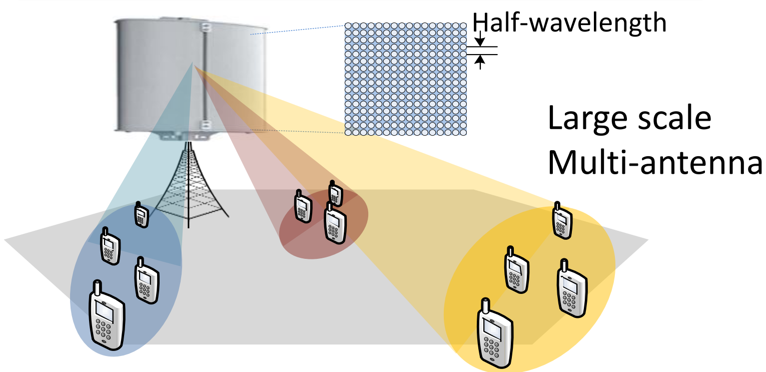
Enhanced Flat NW



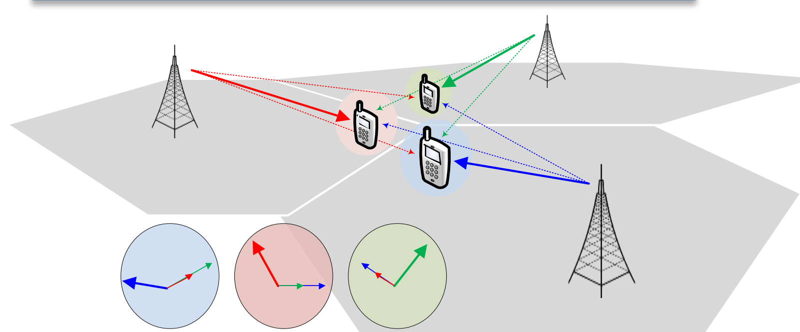
IWK/Integration w/ Wi-Fi



Adv. MIMO/BF (e.g., FD-MIMO)



Interference Management



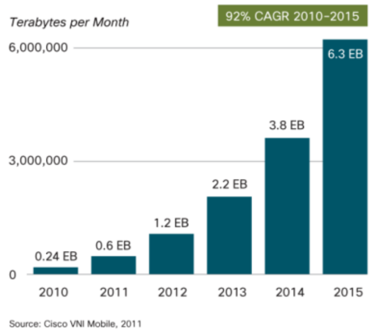
3. Full Dimension MIMO (FD-MIMO)

Full Dimension MIMO (FD-MIMO) for Cellular Bands

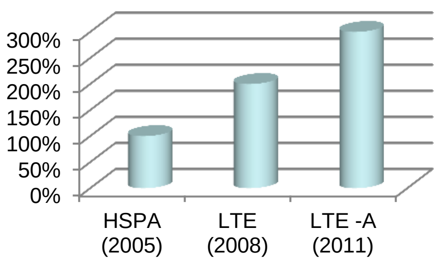
Pain Point

▪State of industry

- 2020, 1000 times traffic increase



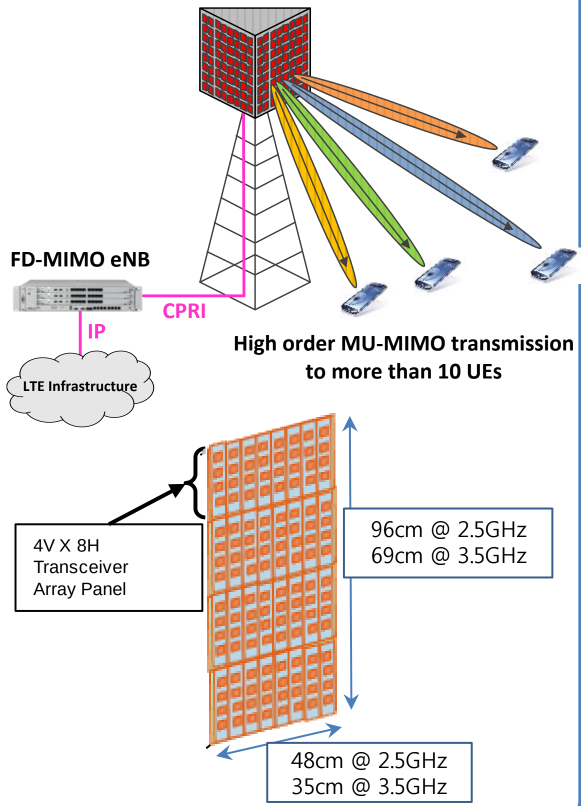
- Need for new innovation



Solution

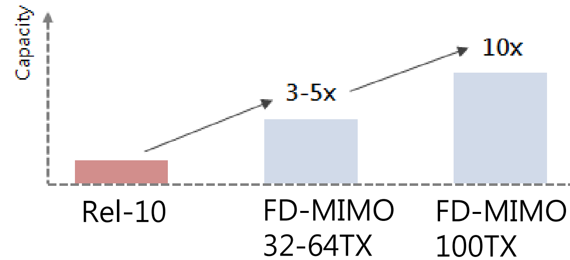
▪ FD-MIMO

1) 2D Active Antenna Array (AAA) up to ~100 antennas at eNB
2) MU-MIMO with 10s of Ues
3) 3D channel model



Benefit

▪ Cell capacity benefit

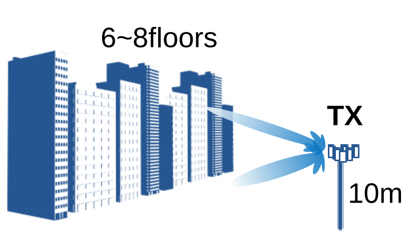


- FD-MIMO is a key technology for path to 5G
- Promising capacity gain for operators and consumers
- Comparable cost to conventional eNB

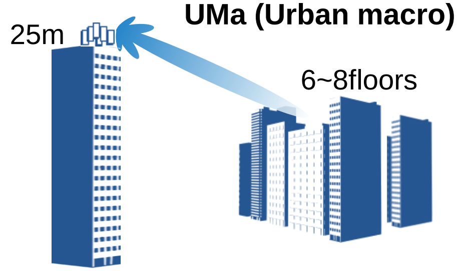
3GPP Study Item on 3D Channel Model (~ June 2014)

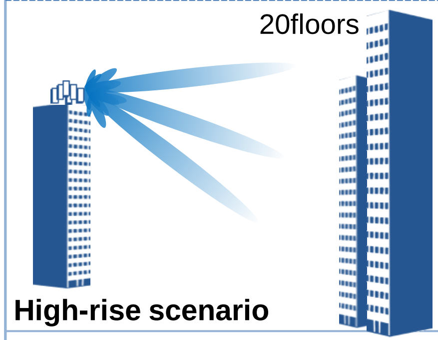
- **New scenarios**

UMi (Urban micro)

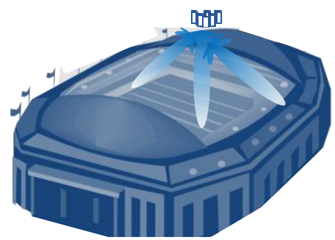


UMa (Urban macro)



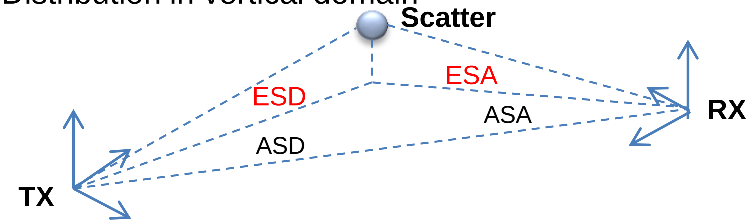


High-rise scenario



Stadium, mall, airport

- **New channel model**
  - Distribution in vertical domain



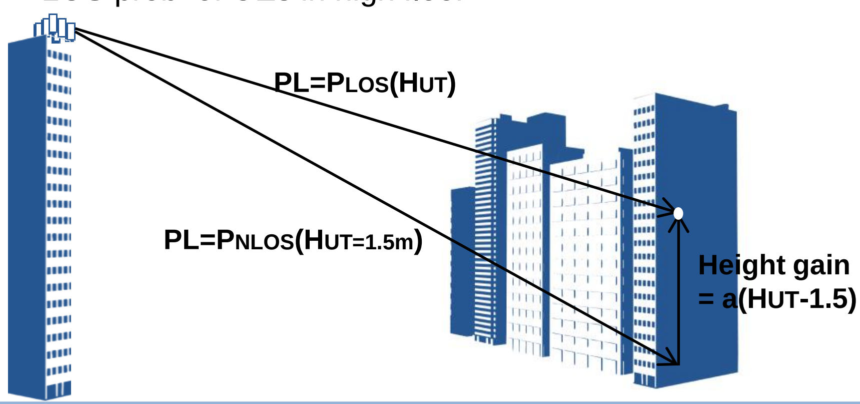
  - Correlation for LS parameter

	DS	K	SF	ASD	ASA
DS	1				
K		1			
SF			1		
ASD				1	
ASA					1

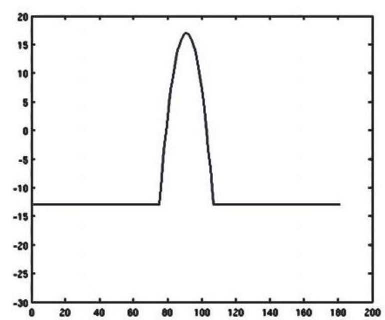
→

	DS	K	SF	ASD	ASA	ESD	ESA
DS	1						
K		1					
SF			1				
ASD				1			
ASA					1		
ESD						1	
ESA							1

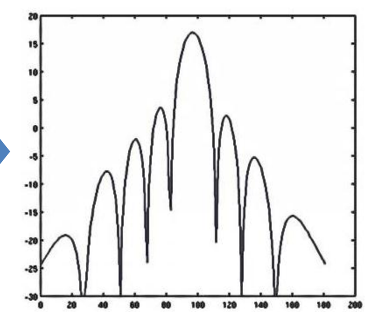
- **New pathloss/LOS prob. model**
  - Pathloss gain for UEs in high floor
  - LOS prob. of UEs in high floor



- **New antenna model**
  - Simplified model → Element generated model
  - Example: 10° vs. M=8 element pattern for vertical domain



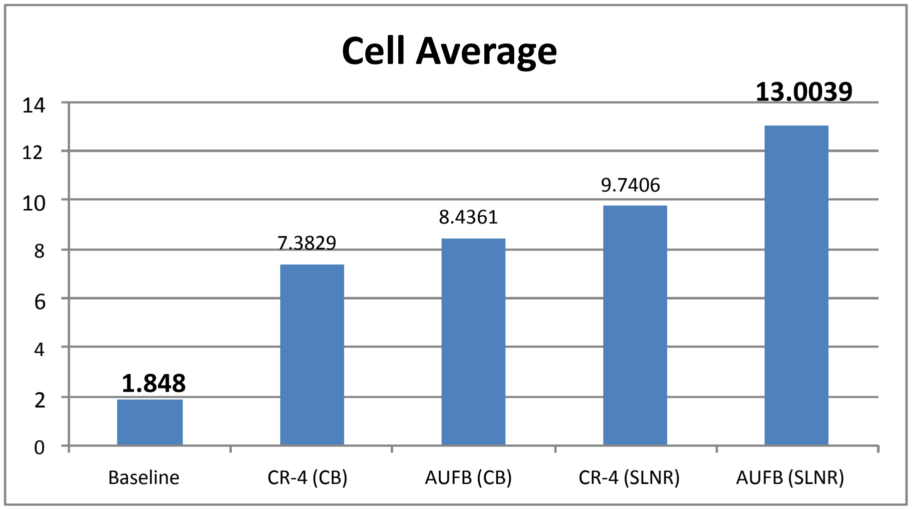
TR36.814

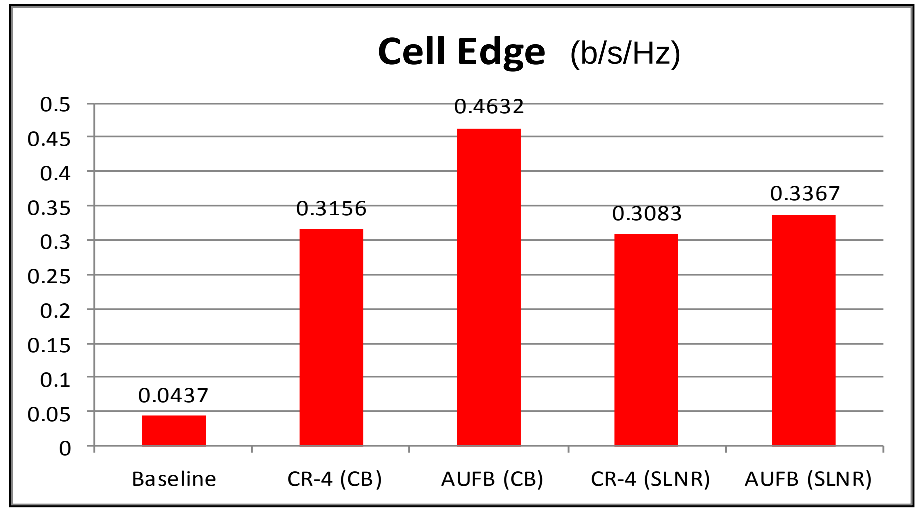


New Model

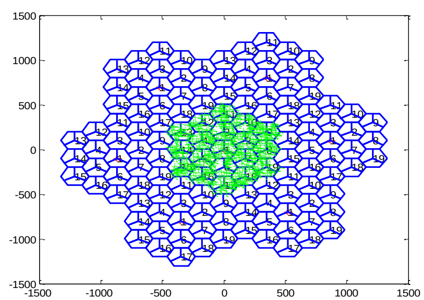
FD-MIMO System Capacity Gain

- In a TDD system, up to **6X** gain for cell average, and up to **10X** for cell edge users
- FD-MIMO: 8H8V at base station, 2 Rx at terminal
- Baseline: Rel-10 4H1V at base station, 2 Rx at terminal





- **AUFB**: All UE full BW
- **CR-4**: Correlation scheduling wi th max 4 UEs
- **CB**: Conjugate beamforming
- **SLNR**: Signal to leakage + noi se ratio



- 3D-UMa, ***up-to-date 3GPP 3D channel model***
- 57 sectors/wraparound, and M=10 2-Rx UEs per sector
- UEs dropped uniformly across floors in 4-8 floor buildings
- UEs dropped 80% Indoor and 20% outdoor (mobility 3kmh)
- Carrier frequency 2GHz, bandwidth 10 MHz
- Full-buffer

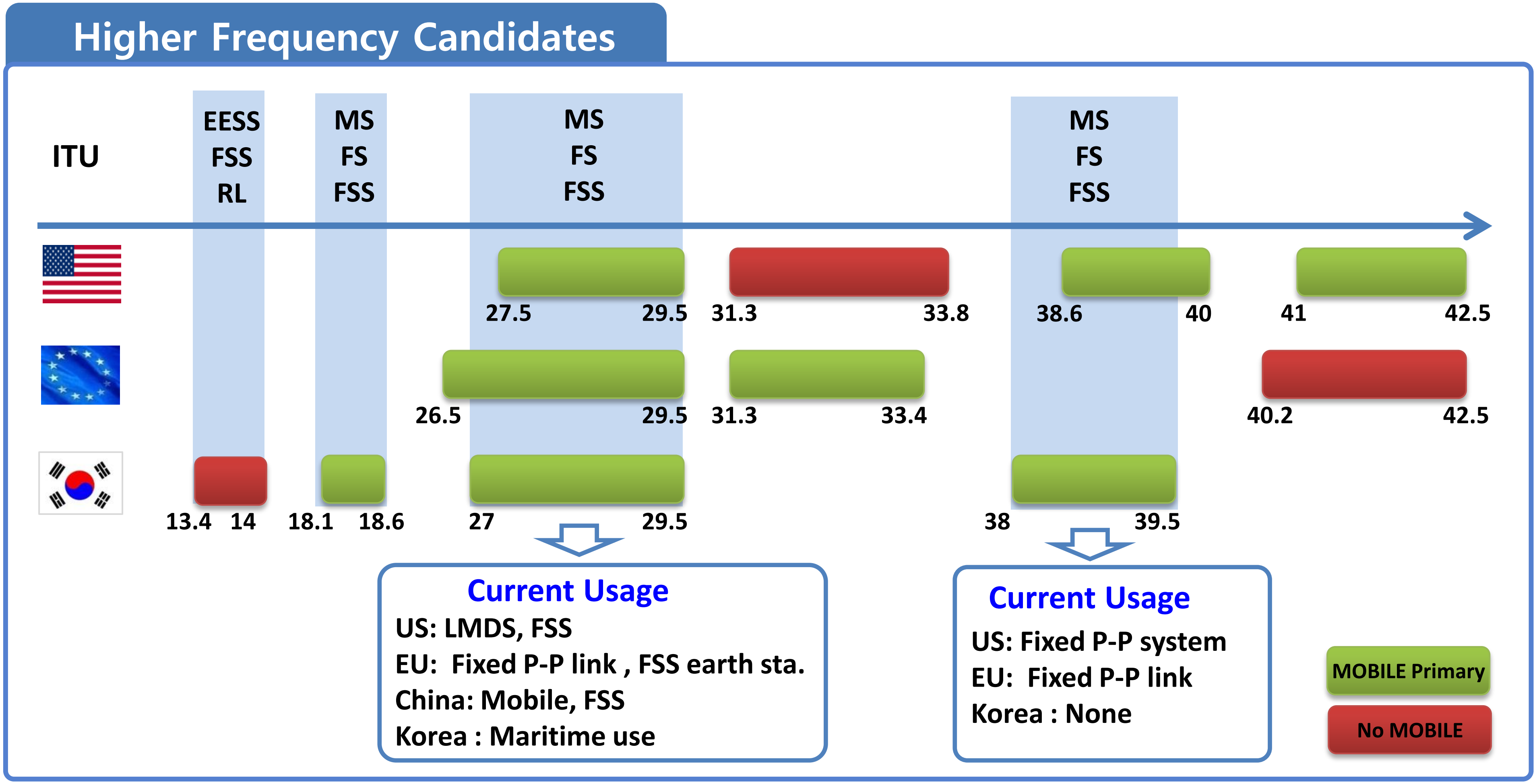
4. mmWave Channel Propagation & Measurements

Spectrum Candidates

SAMSUNG

Candidates for large chunks of contiguous spectrum

- 13.4~14 GHz, 18.1~18.6 GHz, 27~29.5 GHz, 38~39.5 GHz, etc.



EESS (Earth Exploration-Satellite Service) FSS (Fixed Satellite Service) RL (RadioLocation service),
MS (Mobile Service) FS (Fixed Service) P-P (Point to Point) LMDS (Local Multipoint Distribution Services)

Friis' Equation in Free Space (1/4)

Isotropic TX & RX

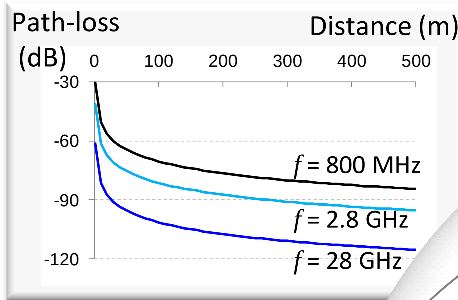
"Path-loss" is proportional to frequency squared

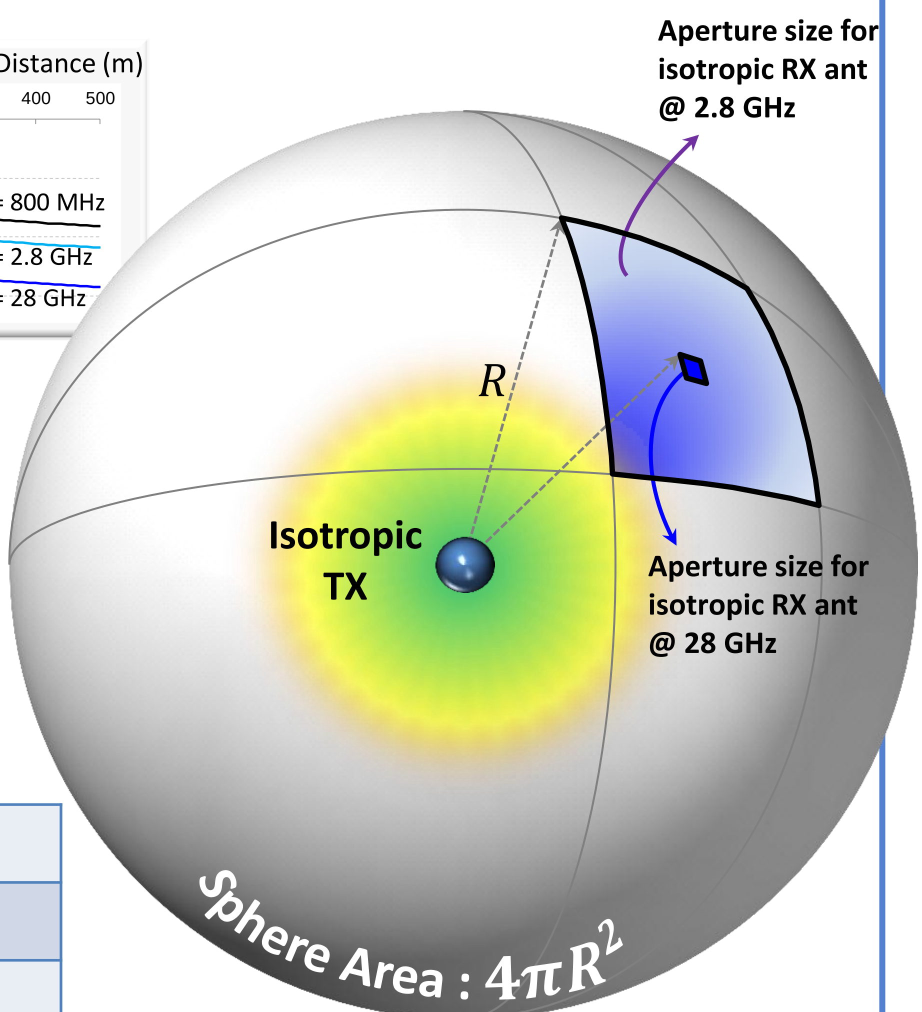
$$P_{RX} = P_{TX} \underbrace{G_{TX} G_{RX}}_{=1 \text{ for isotropic}} \underbrace{\left(\frac{\lambda}{4\pi R}\right)^2}_{\text{Path-loss}}$$

$$= P_{TX} \cdot 1 \cdot 1 \cdot \underbrace{\left(\frac{\lambda^2}{4\pi}\right)}_{\text{Aperture size}} \underbrace{\left(\frac{1}{4\pi R^2}\right)}_{\text{Spherical area}}$$

$$= P_{TX} \cdot 1 \cdot 1 \cdot \left(\frac{c^2}{4\pi \cdot f^2}\right)\left(\frac{1}{4\pi R^2}\right)$$

(c : speed of light)





Comparison example

	2.8 GHz	28 GHz
RX aperture size	9.135 cm^2	0.091 cm^2
Path-loss (R=1m)	-41.4 dB	-61.4 dB

-20 dB

Friis' Equation in Free Space (2/4)

Isotropic TX & Array Antennas for RX

☐ **Same size of RX aperture captures the same RX power regardless of frequency**

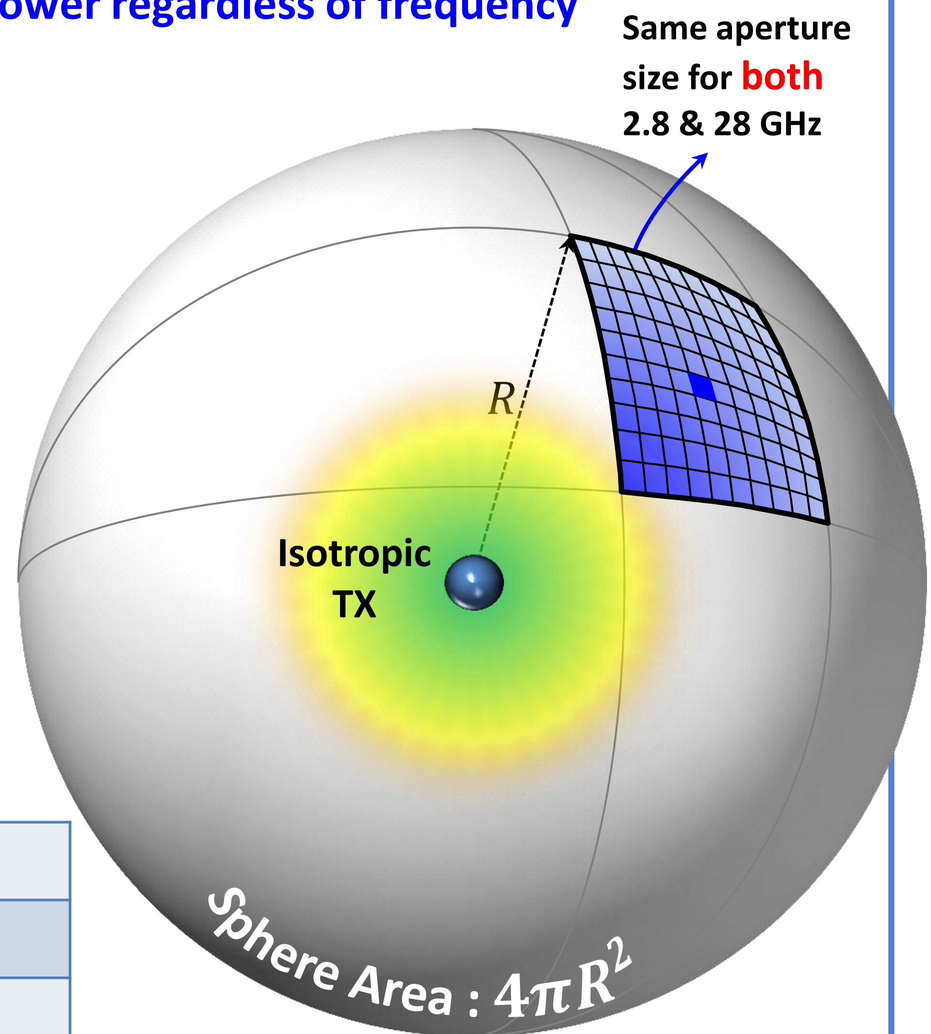
$$P_{RX} = P_{TX} \underbrace{G_{TX}}_{=1 \text{ for isotropic}} G_{RX} \left(\frac{\lambda}{4\pi R} \right)^2$$

$$= P_{TX} \cdot 1 \cdot G_{RX} \left(\frac{\lambda^2}{4\pi} \right) \left(\frac{1}{4\pi R^2} \right)$$

$$\left(G = A_e \frac{4\pi}{\lambda^2} \right)$$

$$= P_{TX} \cdot 1 \cdot A_{e,RX} \left(\frac{4\pi}{\lambda^2} \right) \left(\frac{\lambda^2}{4\pi} \right) \left(\frac{1}{4\pi R^2} \right)$$

$$= P_{TX} \cdot 1 \cdot A_{e,RX} \left(\frac{1}{4\pi R^2} \right)$$



☐ **Comparison example**

	2.8 GHz	28 GHz
RX aperture size	9.135 cm^2	9.135 cm^2
RX power	P_{RX}	P_{RX}

Friis' Equation in Free Space (3/4)

Array Antennas for Both TX & RX

- RX power is even bigger at higher frequency with array antennas for both TX & RX

$$P_{RX} = P_{TX} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi R} \right)^2$$

$$= P_{TX} G_{TX} G_{RX} \left(\frac{\lambda^2}{4\pi} \right) \left(\frac{1}{4\pi R^2} \right)$$

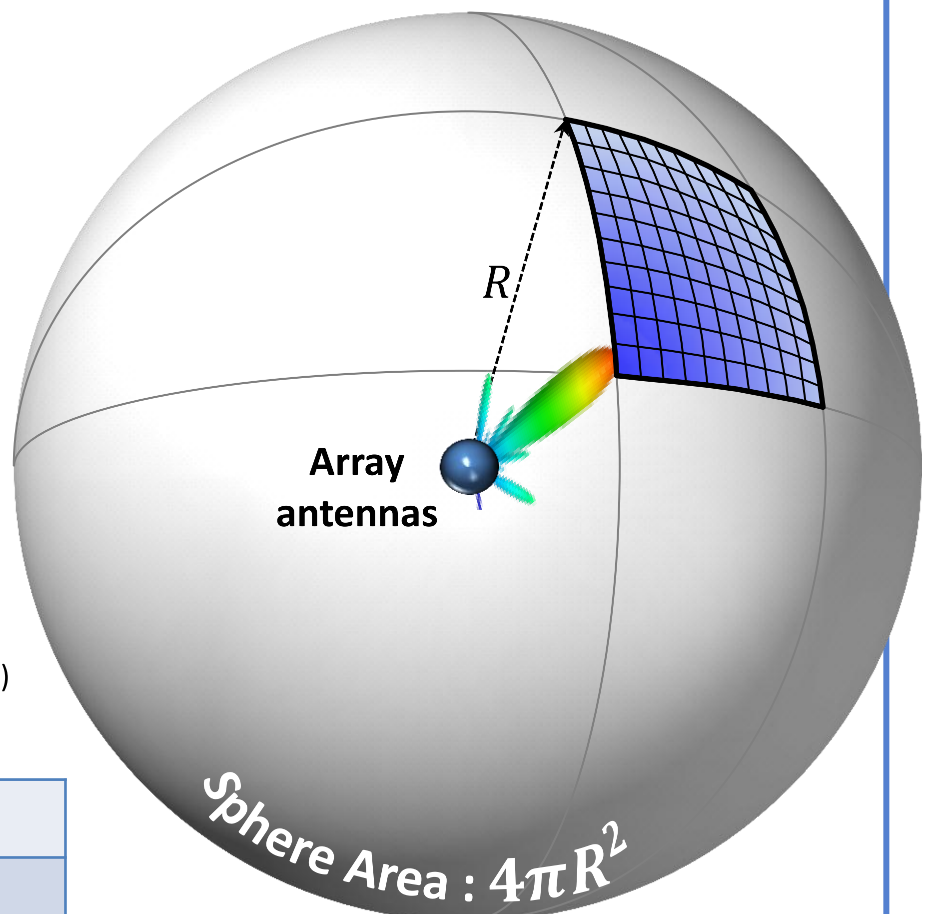
$$\left(G = A_e \frac{4\pi}{\lambda^2} \right)$$

$$= P_{TX} A_{e,TX} A_{e,RX} \left(\frac{4\pi}{\lambda^2} \right) \left(\frac{4\pi}{\lambda^2} \right) \left(\frac{\lambda^2}{4\pi} \right) \left(\frac{1}{4\pi R^2} \right)$$

$$= P_{TX} A_{e,TX} A_{e,RX} \left(\frac{4\pi}{\lambda^2} \right) \left(\frac{1}{4\pi R^2} \right)$$

$$= P_{TX} A_{e,TX} A_{e,RX} \left(\frac{4\pi \cdot f^2}{c^2} \right) \left(\frac{1}{4\pi R^2} \right)$$

(c : speed of light)



- Comparison example

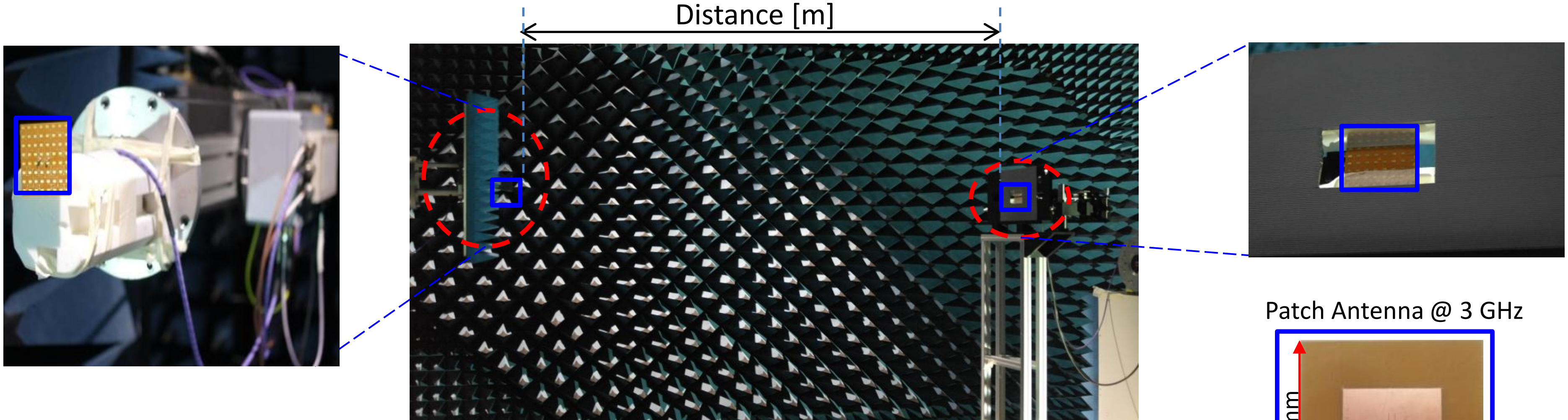
	2.8 GHz	28 GHz
RX power	P_{RX}	P_{RX} + 20 dB

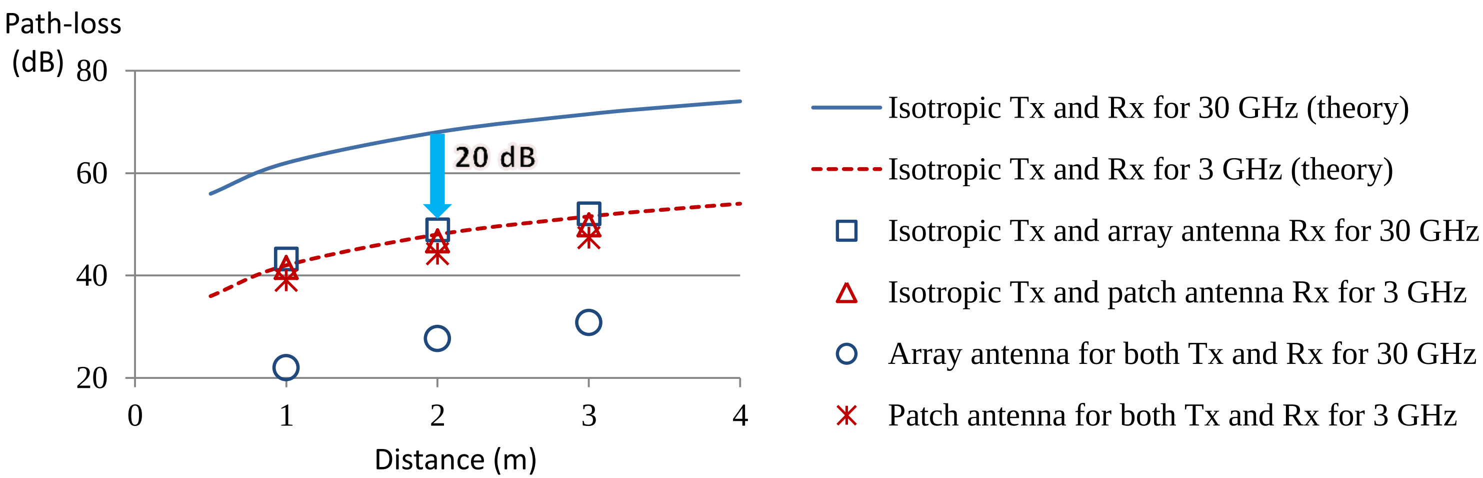
+ 20 dB

Friis' Equation in Free Space (4/4)

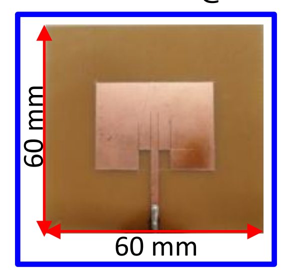
Path-loss Measurement

☐ **Same size of RX aperture captures the same RX power regardless of frequency**

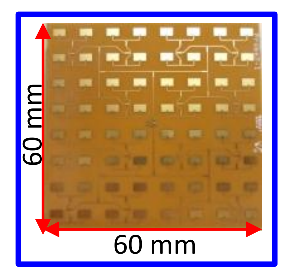




Patch Antenna @ 3 GHz



Array Antenna @ 30 GHz

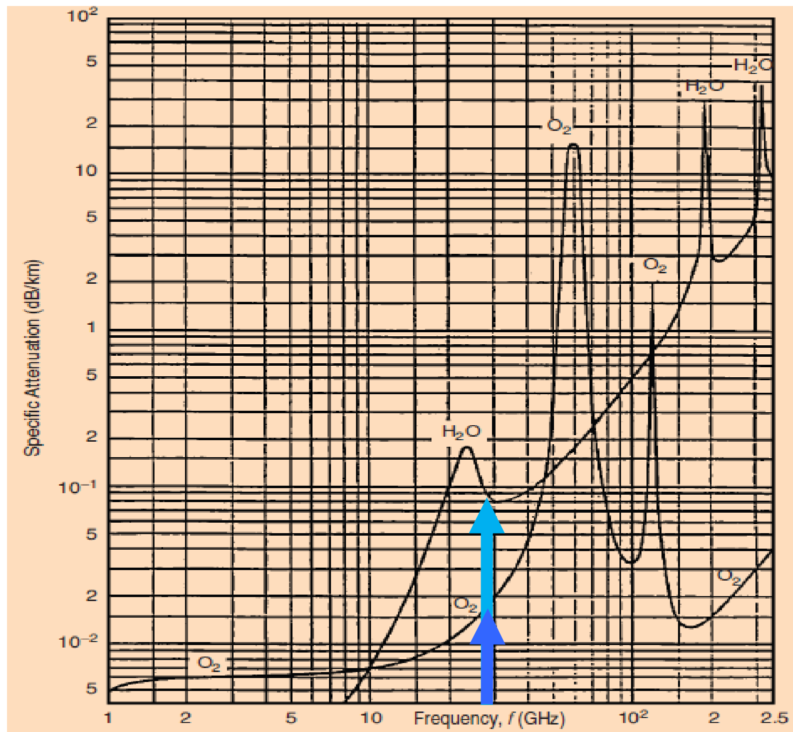


Atmospheric Absorption Loss

- **Atmospheric absorption loss due to H_2O & O_2 at 28 GHz is negligible**

Atmospheric Absorption

- ☐ **H_2O absorption @ 28 GHz is about 0.09 dB/km (=0.018 dB/200 m)**
- ☐ **O_2 absorption @ 28 GHz is about 0.02 dB/km (=0.004 dB/200 m)**



[Specific attenuation due to oxygen and water vapor]

Pressure: 1013 mb
Temperature: 15 °C
Water Vapour: 7.5 μm^2

[Conditions]

[Ref.] M. Marcus and B. Pattan. Millimeter wave propagation: spectrum management implications. *IEEE Microwave Magazine*, June 2005.

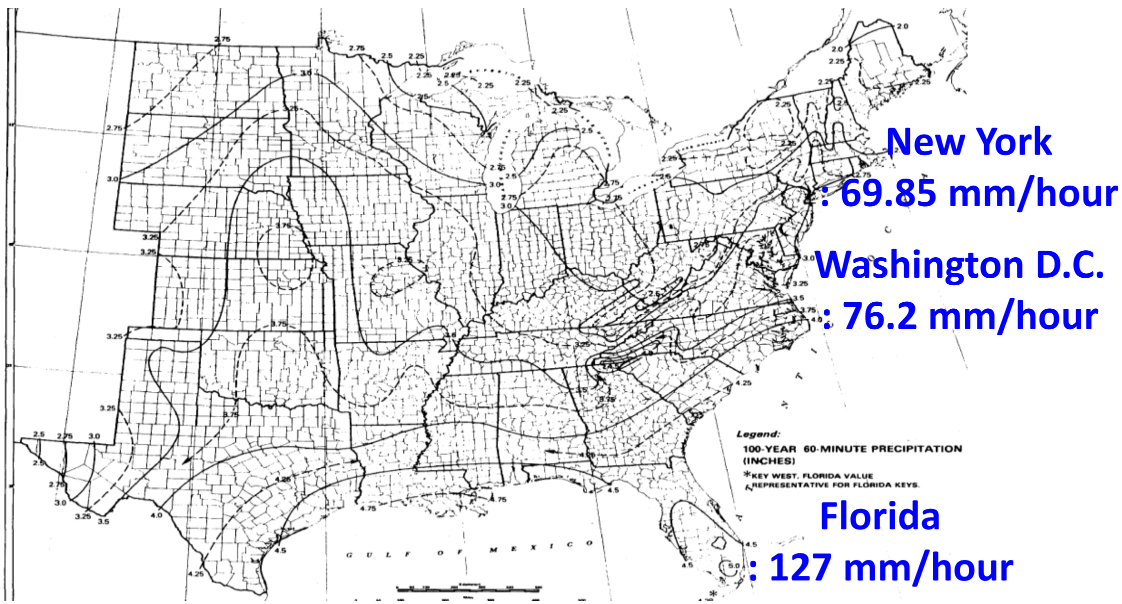
Precipitation Loss

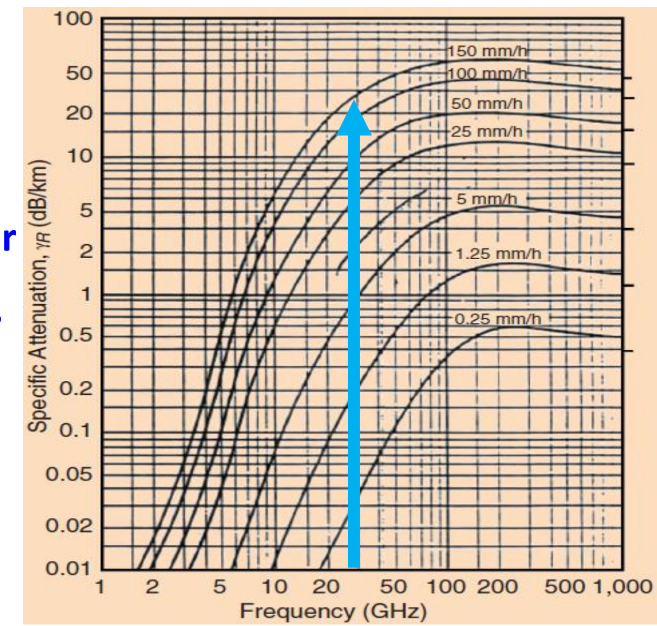
- **At 28GHz, approximately 4 dB at 200 m even for 110 mm/hour intensity**

Precipitation Loss

- ☐ **100-year recurrence 1-hour rain intensity is approximately 110 mm/hour (Seoul, Korea)**
- ☐ **100-year recurrence 1-hour rain intensity is approximately 70-127 mm/hour (US east cost)**

100-year recurrence 1-hour rain intensity (US east cost)





[Attenuation due to rain]

[Ref.] http://www.nws.noaa.gov/ohd/hdsc/On-line_reports/
[Ref.] M. Marcus and B. Pattan. Millimeter wave propagation: spectrum management implications. *IEEE Microwave Magazine*, June 2005.

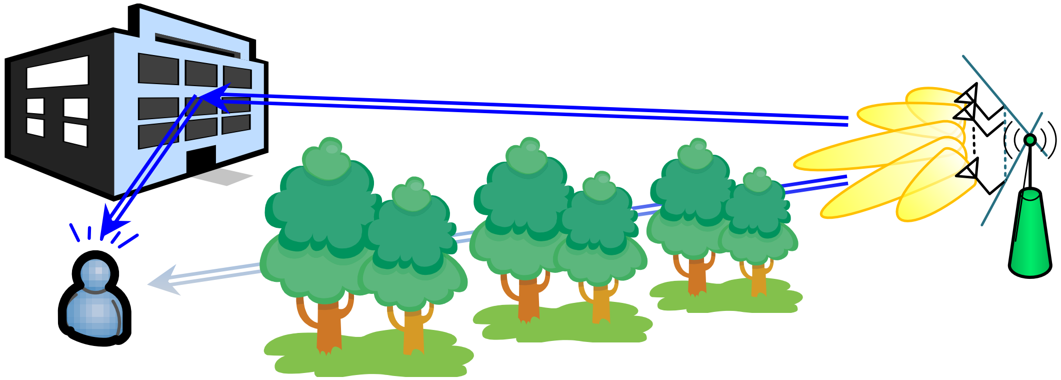
Foliage Loss

- **Loss in dense foliage is not negligible, but other reflection paths are expected in urban environments**

Foliage Loss

☐ **Additional loss of 28 GHz compared to 2.8 GHz: 3.3 dB (2 m foliage), 8.6 dB (10 m foliage)**

- In urban environments, other reflection paths are highly expected from surroundings



Empirical relationship for loss :

$$L_{foliage} = 0.2 f^{0.3} D^{0.6} \text{ dB}$$

where

f : frequency in MHz,

D : depth of foliage transverse in meters (D < 400 m)

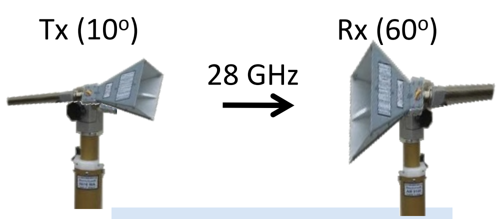
[Ref.] M. Marcus and B. Pattan. Millimeter wave propagation: spectrum management implications. *IEEE Microwave Magazine*, June 2005.

Channel Measurement – Sub-Urban

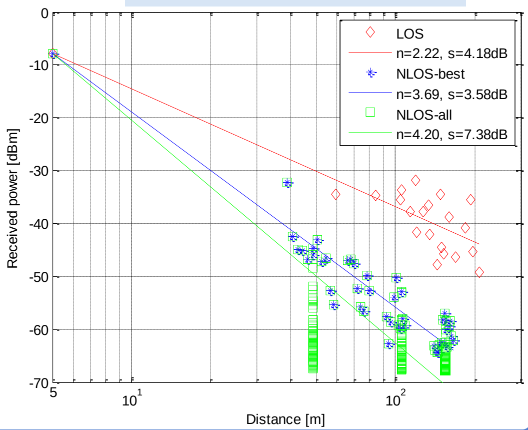
- **Similar path-loss exponent & smaller delay spread measured** (w.r.t. current cellular bands)
  - Measurements were made by using horn-type antennas at 28 GHz and 38 GHz in 2011

Samsung Campus, Korea

		LOS	NLOS
Path Loss Exponent		2.22	3.69
RMS Delay Spread [ns]	Median	4.0	34.2
	99%	11.4	168.7

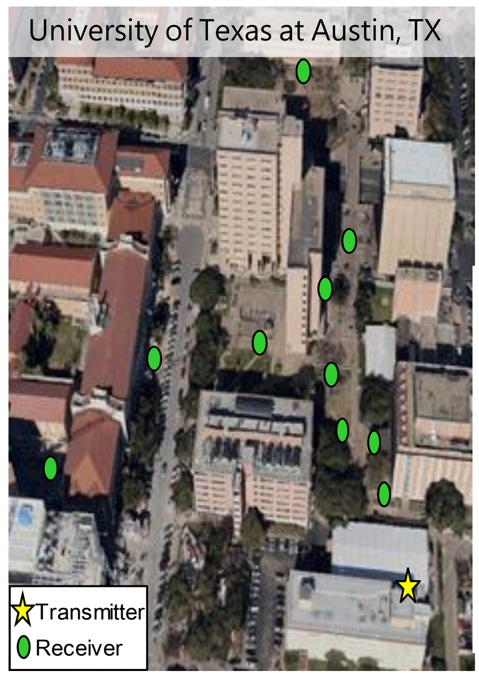


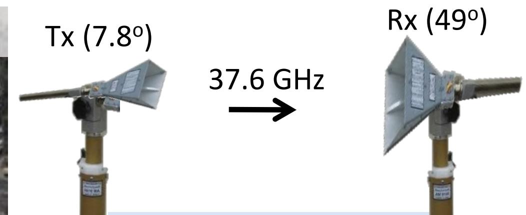
[Received Power]



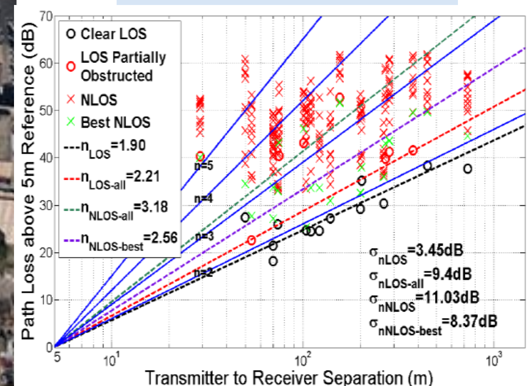
UT Austin Campus, US

		LOS	NLOS
Path Loss Exponent		2.21	3.18
RMS Delay Spread [ns]	Median	1.9	15.5
	99%	13.7	166





[Received Power]



* Reference : Prof. Ted Rappaport, UT Austin, 2011

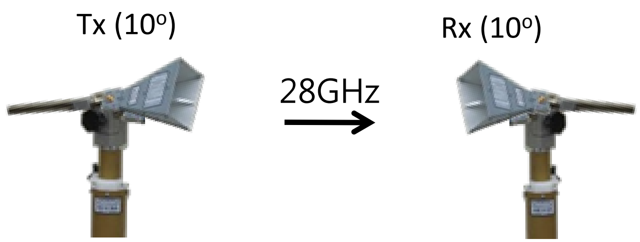
Channel Measurement – Dense Urban

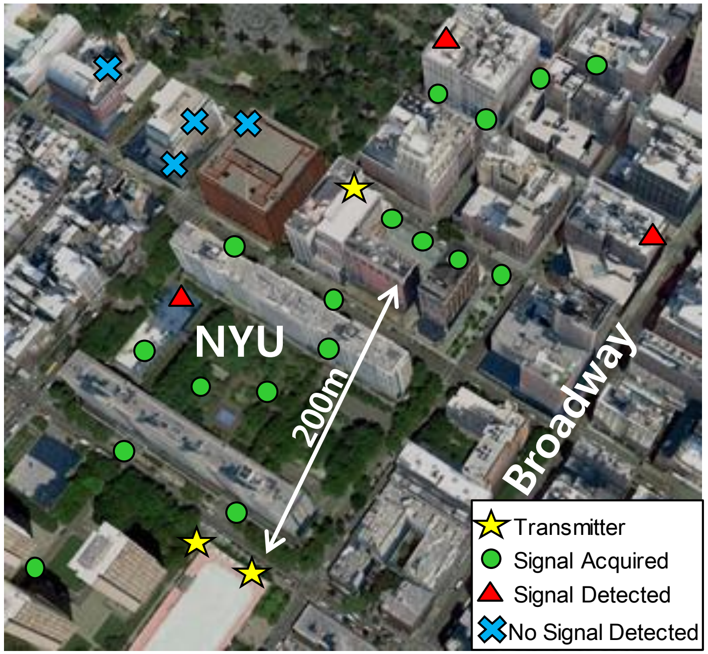
- **Slightly higher but comparable path loss measured in New York City in 2012**

Manhattan, New York, US

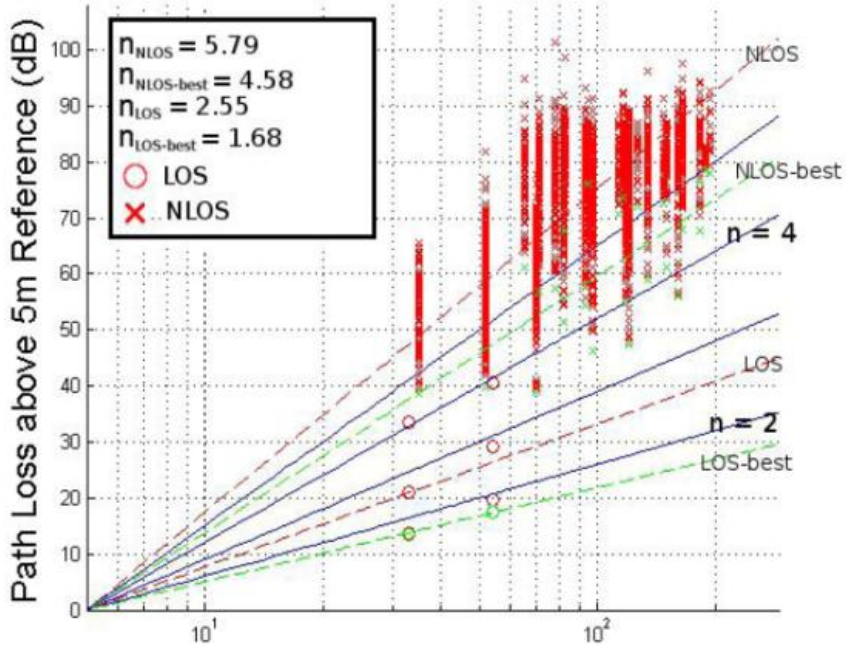
- **Reference : Prof. Ted Rappaport, NYU, 2012**
  - T. S. Rappaport et.al. "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!", IEEE Access Journal, May 2013

	LOS	NLOS
Path Loss Exponent	**1.68**	**4.58**
Delay Spread [ns]	**Expected to be larger than the previous, But to be still smaller than current bands**	





[New York, Manhattan – NY University]



[Path Loss]

Channel Measurement – Indoor

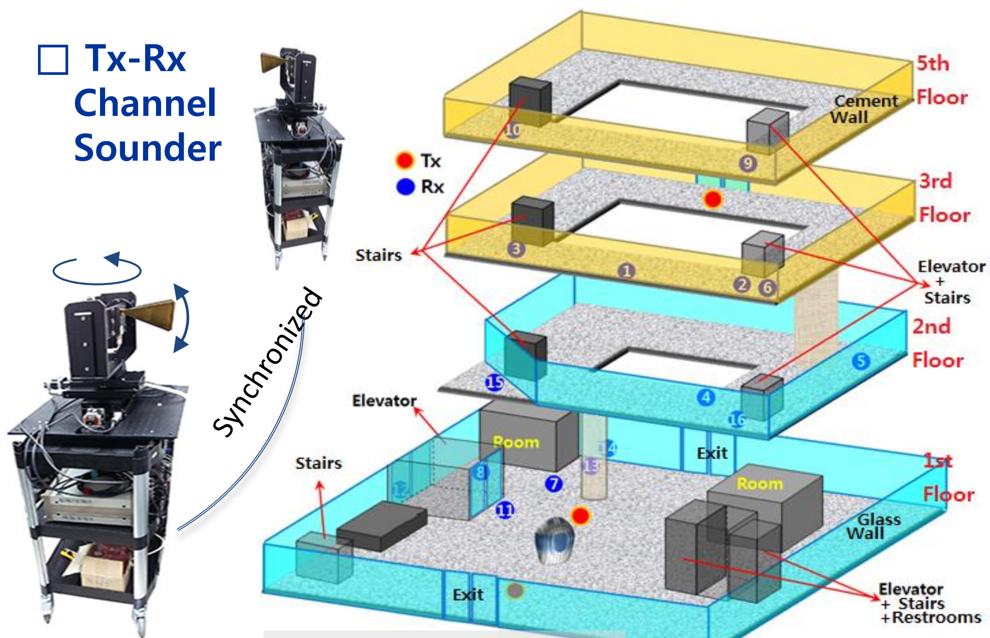
- **Channel measurement for indoor environment being conducted in Korea**

Channel Sounder and Structure Map

☐ **Measurements at Total 16 Rx Locations**

- ✓ Tx-Rx Distance : 10m ~ 40m
- ✓ Max. RMS delay spread : 83.7 [ns] at location 13

☐ **Tx-Rx Channel Sounder**



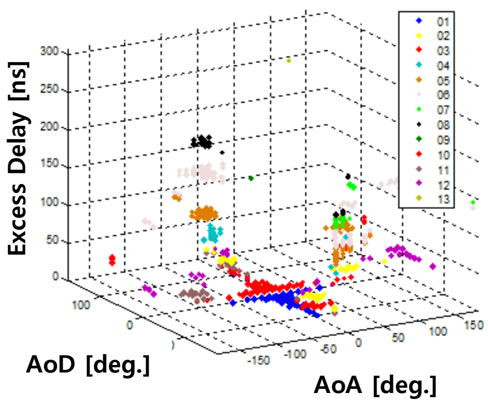
[KAIST KI Bldg., Korea]

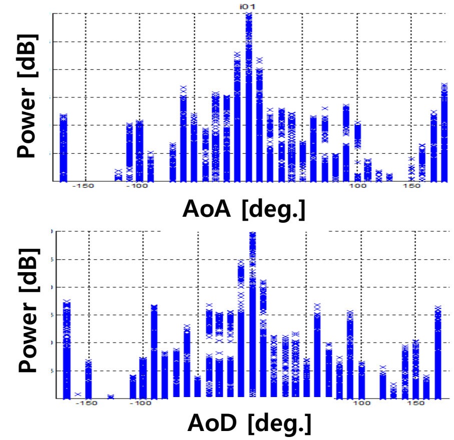
Scenery & Exemplary Model at 3rd FL

☐ **Perspective from the 3rd FL Tx Location**

☐ **Exemplary Channel Parameter Modeling (location 1)**

- ✓ Clustering
- ✓ AoA/AoD Power Distribution





5. mmWave Beamforming Prototype & Test Results

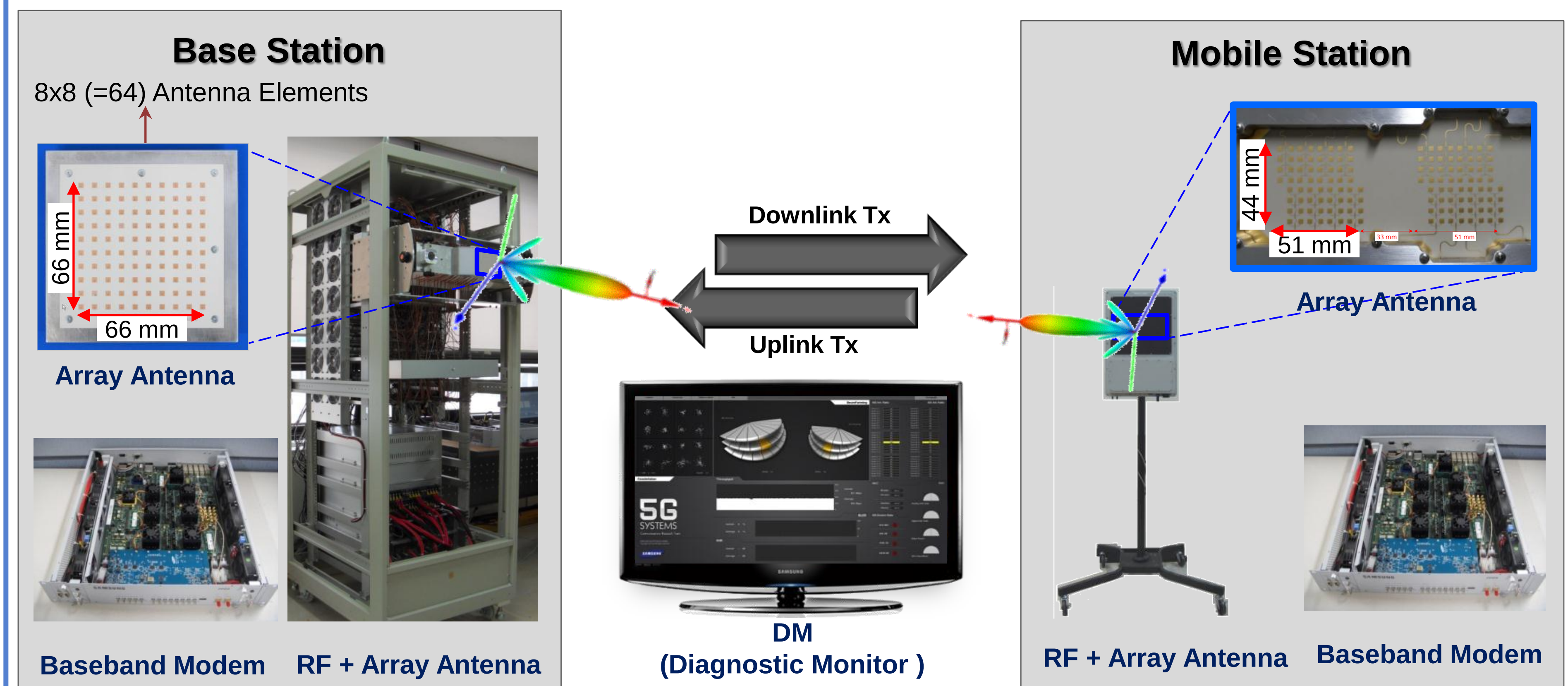
mmWave Beamforming Prototype

SAMSUNG

- **Enabler for mmWave mobile communication**
  - Adaptive array transceiver operating in the millimeter-wave frequency bands for outdoor environment

Carrier Frequency	27.925 GHz
Bandwidth	500 MHz
Max. Tx Power	37 dBm
Beam width (Half Power)	10^{o}

mmWave BF Prototype



Test Results of mmWave Beamforming Prototype

Performance tests of mmWave OFDM prototype

- OFDM system parameters designed for mmWave bands
- Indoor & outdoor measurements performed for different data rates and transmission ranges

System Parameters & Test Results

PARAMETER	VALUE
Carrier Frequency	27.925 GHz
Bandwidth	500 MHz
Duplexing	TDD
Array Antenna Size	8x8 (64 elements) 8x4 (32 elements)
Beam-width (Half Power)	10°
Channel Coding	LDPC
Modulation	QPSK / 16QAM

PARAMETER	VALUE	REMARKS
Supported Data Rates	1,056Mbps 528Mbps 264Mbps	
Max Tx Range	Up to 2km @ LoS	>10 dB Tx power headroom

UHD & Full-HD Video Streaming

Measurements with DM

Test Results – Range

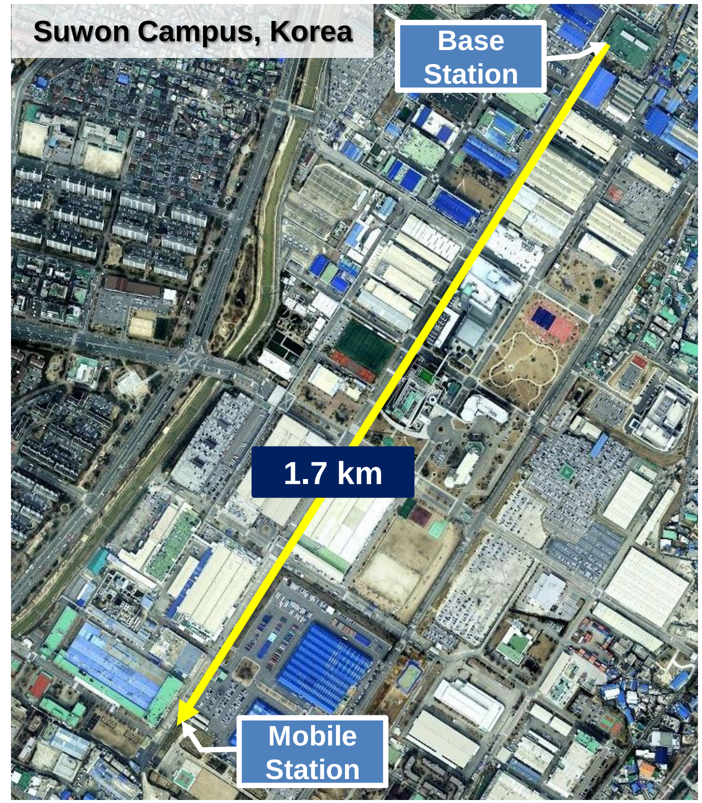
Outdoor LoS range test

- Error-free communications possible at 1.7 km LoS with > 10dB Tx power headroom
- Pencil beamforming at both transmitter and receiver supporting long range communications

LoS Range

☐ **Support wide-range LoS coverage**

- ✓ 16-QAM (528Mbps) : BLER 10^{-6}
- ✓ QPSK (264Mbps) : Error Free



BLER : Block Error Rate QPSK : Quadrature Phase Shift Keying QAM : Quadrature Amplitude Modulation

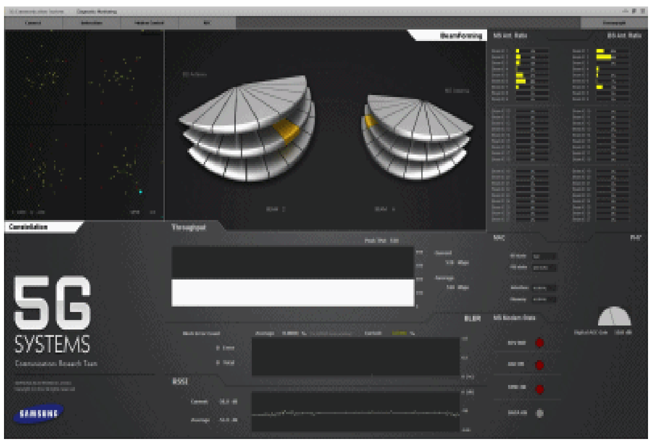
Test Results – Mobility

- **Outdoor NLoS mobility tests**
  - Adaptive joint beamforming & tracking supports 8 km/h mobility even in NLOS

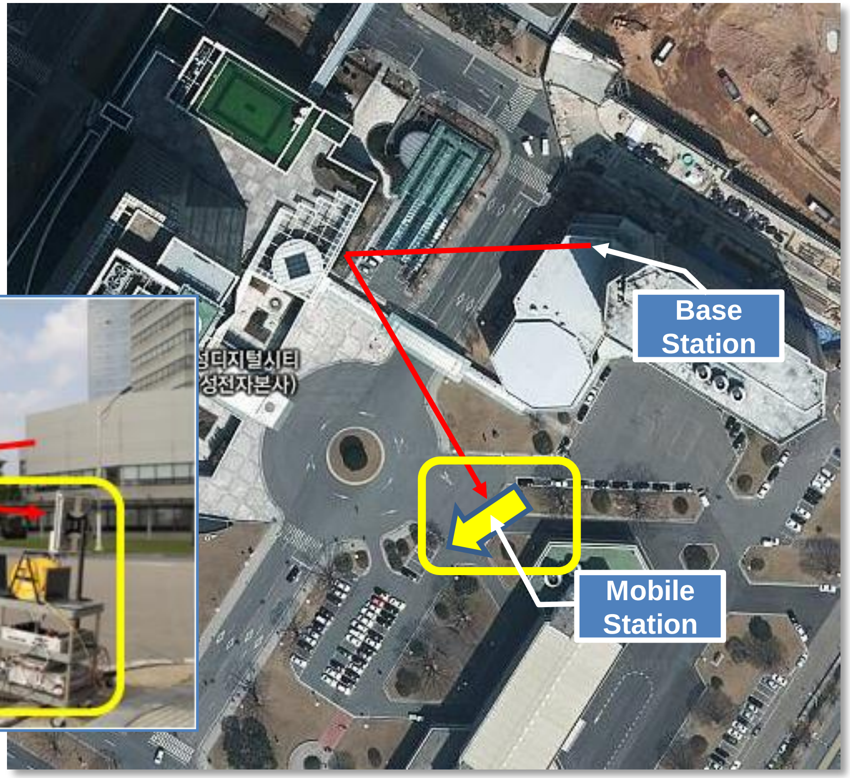
Mobility Support in NLoS

☐ **Mobility support up to 8 km/h at outdoor NLoS environments**

- ✓ 16-QAM (528Mbps) : BLER 0~0.5%
- ✓ QPSK (264Mbps) : Error Free



[DM Screen during Mobility Test]



Test Results – Building Penetration

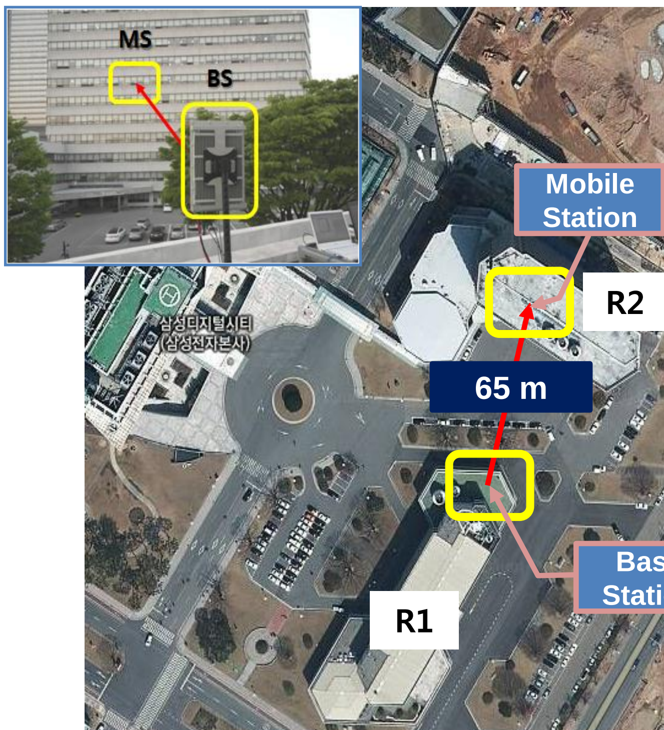
Outdoor-to-indoor penetration tests

- Indoor MS can successfully receive most signals sent from outdoor BS
- Outdoor-to-indoor penetration made through tinted glasses and doors

Outdoor to Indoor #1

☐ **Signal measured inside office on 7th FL of R2**

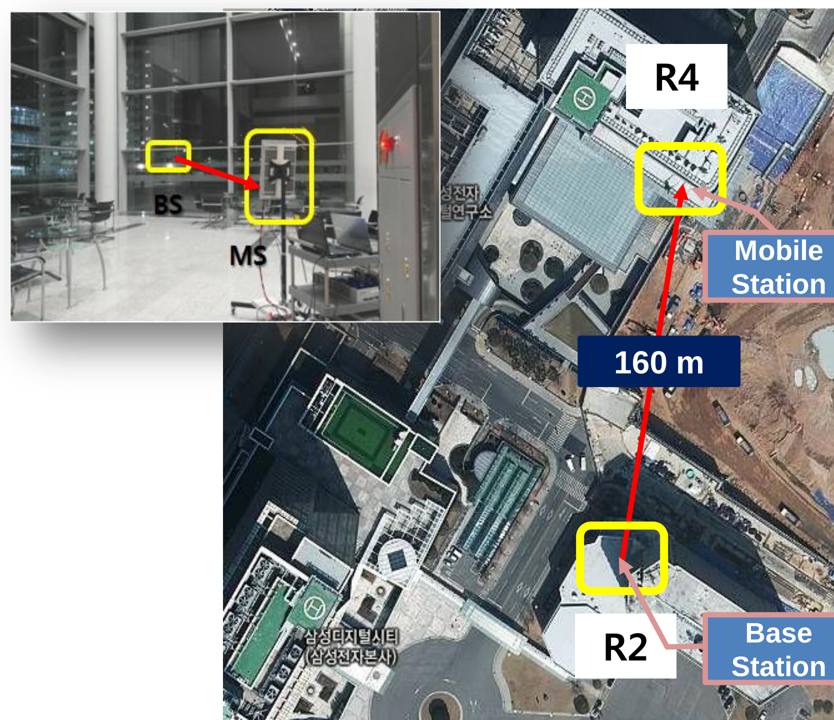
- QPSK : BLER 0.0005~0.6% (Target : < BLER 10%)



Outdoor to Indoor #2

☐ **Signal measured inside the lobby at R4**

- QPSK : BLER 0.0005~0.3% (Target : < BLER 10%)



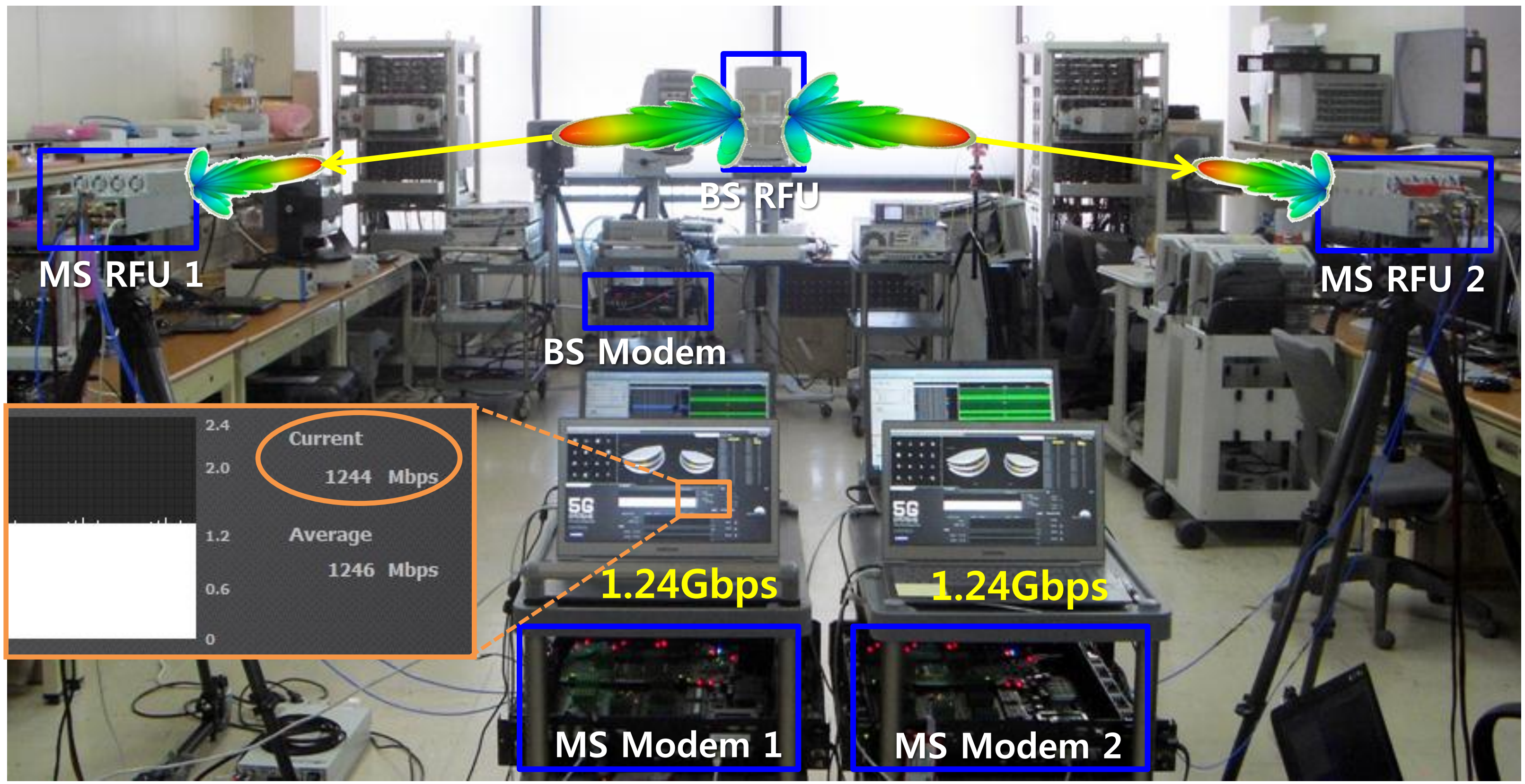
Multi-User Support

Multi-User Communication Tests

- - 2.48 Gbps aggregate throughput in MU-MIMO mode

PARAMETER	VALUE
Carrier Frequency	27.925 GHz
Bandwidth	800 MHz
Max. Tx Power	37 dBm
Beam-width (Half Power)	10º
Multiple Antenna	2x2 MIMO

MU-MIMO Configuration



Summary

- **FD-MIMO to provide 4-5x capacity compared to existing LTE-Adv**
  - 2D Active Antenna Array (AAA) at eNB with MU-MIMO of 10s of UEs
  - Comparable cost to conventional eNB
  - 3GPP study item on 3D channel model to be developed until December 2013

- **mmWave BF technology as a viable solution to provide Gbps experience**
  - Promising mmWave channel measurement data obtained and modeling to follow
  - Encouraging results of outdoor coverage and indoor penetration tests shown
  - Real-time adaptive beamforming and tracking implemented to show mobility support

5G = more productive society and a better world